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Computer assisted analysis of
auroral images obtained from
high altitude polar satellites

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Abstract

We developed automatic techniques that allow the extraction of physically significant parameters from auroral images. This allows the processing of a much larger number of images than is currently possible with manual techniques. We applied our techniques to diverse auroral image datasets. We made these results available to geophysicists at NASA and at universities in the form of a software system that performs the image analysis. After some feedback from users, we transferred an upgraded system to NASA and to two universities. We demonstrated the feasibility of user-trained search and retrieval of large amounts of image data using our automatically derived parameter indexes. We developed and applied techniques based on classification and regression trees (CART) to broaden the types of images to which the automated search and retrieval may be applied. We tested our techniques with DE-1 auroral images.

1 Research results for the project

1.1 Introduction

Our CESDIS research involved a collaboration between computer scientists and electrical engineers interested in researching and understanding practical computer image analysis algorithms and geophysicists interested in the use of these tools to enable them to study the vast quantities of data available from NASA satellites. The project provided benefits to both communities of researchers. It allowed the image analysis researchers to make realistic assumptions about the data during their research on the algorithms. The ability to test the algorithms with large sets of satellite images ensured that the “right” problems were solved. The geophysicists in turn gained tools that allows them to quickly study the vast amounts of data that would otherwise remain unused. This final report describes the results of the past several years of research in developing and evaluating the tools to process images of the Earth’s aurora, and in transferring these tools to the users.

1.2 Developing the tools

The first task of the project was to obtain the data: DE-1 satellite images from the University of Iowa and VIKING satellite images from the University of Calgary. The necessary infrastructure was built in order to manipulate these images with the Stanford image processing systems. The decision was made to concentrate first on one data set to demonstrate the feasibility of computer processing of these types of auroral images. The DE-1 satellite images were selected because over 500,000 have been gathered. We obtained 1000 of these images for our tests and we gained the experience necessary to process them.

1.2.1 Standard techniques

Many of the standard techniques available from image processing and computer vision were applied to the DE-1 images. These standard techniques did not provide for adequate performance with these images. The problems that were identified were the uneven solar illumination in the images, the dynamic changes in shape and location of the aurora and the requirement for many

diverse measurements and parameters by the geophysicists [Ref. 1,4]. It was determined that recovering the inner auroral boundary and the outer auroral boundary would provide a description of the images rich enough to allow many different measurements and parameters to be calculated. We began working on finding the inner auroral boundary using the computer. This inner boundary allows the determination of the magnetic field within the polar cap (the region within the inner boundary of the aurora). This magnetic field quantity is a fundamental parameter needed by geophysicists to study the flow of energy through the solar wind - magnetosphere - ionosphere system.

1.2.2 Newly developed techniques for boundary finding

Scientific images require a different set of assumptions than those for other computer vision applications. The assumptions of rigid bodies and of simple shapes for objects is valid for many industrial applications, but it is not valid for the auroral images (nor for most other scientific applications). For this reason, the decision was made to extend and apply to the images a technique called "snakes", the fitting of an elastic curve to the data, for finding the boundaries. Several problems arose during the application of snakes to the auroral images. Our contributions to the solutions of these problems include the extension of snakes to apply to objects with changing topologies, the understanding of the stability of snakes, and the development of "adaptive snakes" that allow the automatic setting of snake parameters. These extensions substantially increase the number of applications for which snakes are a viable computer processing technique [Refs. 6,7]. Recently, a medical imaging company has adapted the algorithm described in [Ref. 6] for possible use with their ultrasound instruments.

The snakes were tested extensively with the DE images. The results were compared to manual measurements, which were used as a "gold" standard [Refs. 8,9,10]. The performance of the snakes was found to be adequate for winter hemisphere scenes, but it was not adequate for the summer hemisphere scenes.

For this reason, a new optimization approach to the boundary finding was developed based on a cartesian to polar conversion of the data. The new technique first finds the best fit ellipse, in a weighted least square sense, to the image data. This best fit ellipse is then used as an initial estimate for a second stage of processing that removes the requirement that the fit be to an

ellipse. The second stage has been developed in two alternate ways, the first using the snakes previously described, and the second using a line-by-line processing technique in the polar coordinate domain. This new technique allows the extraction of the auroral boundaries for both winter and summer scenes. We show an example of the application of this technique in the next section.

We also developed interactive methods for finding boundaries. We wrote an X-windows based software system for interactive modification of boundaries. This was used both to generate manual boundaries for use as gold standards, and also for modification of automatically generated boundaries, when that was needed. Finally, we developed a novel way to find boundaries from images interactively by combining standard image processing techniques with manual techniques [Ref. 3].

1.2.3 Newly developed image retrieval techniques

As mentioned above, the automation of the boundary extraction step in auroral image analysis allows the extraction of quantitative parameters from much larger sets of images. The user naturally wishes to query these large databases on the basis of the extracted quantitative parameters. Since the users' requirements vary from person to person, and from day to day, we developed algorithms and techniques that allow the user-trained query of information based on image content [Ref. 4]. Our work here is complementary to image browsing systems that are currently under development by others. Our work offers the capability of search and retrieval based on quantitative measures from the images. This extends the capabilities of most browse systems that do not allow quantitative extraction of information.

We developed algorithms based on classification and regression trees (CART) [Ref. 4] to select images from the larger database. CART combines many unique abilities: it can handle hundreds of variables, including both non-numerical and numerical ones, processes missing data in a simple, effective manner, it is designed to perform well with previously unseen data, it is efficient, it is trained by examples and it supports the users' understanding of the data selection decisions. This last point is most important: CART can be used in the same manner as neural networks but the results of the CART decisions are easily interpreted by the scientific users.

We used CART to combine many diverse parameters and features that

were derived by our auroral boundary extraction system. We used the CART algorithm, together with required auroral parameter extraction interfaces required to drive the CART system. An interactive parameter selection system based on X-windows was written. This facilitated the formation of queries by the user. The user “queries” the system by providing examples of images or parameters of interest. The system “replies” by retrieving datasets similar to the ones presented during the query. The performance of the system was tested by using gold standards provided by manual replies extracted for the queries [Ref.4]. We used many DE satellite images for this phase of the study.

2 Applying the tools

The measurement of the inner boundary can be used to derive the magnetic flux within the polar cap. This quantity is a fundamental parameter needed by the geophysicists. There is a need to convert the results to the proper geometries and units of measurement. Two summer students helped with these tasks. Steve Ross developed a system to remap the auroral image sequences to image sequences from a fixed viewpoint. This system allows the motion due to the satellite to be removed, leaving only the residual motion due to the dynamics of the aurora. Chacko Sonny started developing a system to allow the measurements of surface area and the incorporation of a magnetic field model to allow the determination of magnetic flux. Domingo Mihovilovic completed this work to allow the extraction of magnetic flux in Webers. This, together with an estimate of the area of the polar cap, allows the recovery of information useful to the scientists, e.g. the magnetic flux through the polar cap region.

2.1 Technology transfer of auroral image analysis

With the help of Dr. Robert McGuire of NSSDC at Goddard we identified the Coordinated Data Analysis Workshop (CDAW) 9 dataset as a useful dataset for testing our techniques and for providing our results to the NASA scientific community. We obtained the CDAW 9 dataset from Dr. John Craven of the University of Iowa. We completed our analyses with this dataset and provided the processed information to Dr. Clauer at the University of Michigan, Dr. McGuire at NSSDC and to Dr. Craven at the University of

Iowa for their evaluation.

Figure 1 shows part of the CDAW 9 dataset to which we have applied our polar coordinates algorithm. This figure shows a sequence of fifteen DE-1 images gathered on May 4, 1986. The sequence is displayed in column scan order, from top left to bottom left and then from top right to bottom right. Overlaid on the images are the inner boundaries automatically generated using our polar coordinates processing system. The inner boundaries are adequately found in all of these images. The boundaries appear to grow as time progresses but this is partly due to the satellite moving closer to the Earth. Removing the effects of the satellite motion and using the IGRF magnetic field model for the Earth allows us to provide physical parameters from our automated processing. Figure 2 shows a time series plot of the integrated magnetic flux within the auroral oval for each of the fifteen images. The removal of the satellite motion reveals the underlying temporal changes in the magnetic field strengths.

Dr. McGuire of NSSDC aided us in installing our software at NSSDC onto their sun workstation. Dr. Robert Clauer made contact with Dr. Marsha Torr of NASA Marshall Space Flight Center regarding the application of our techniques to the auroral images expected from the upcoming Global Geospace Sciences (GGS) mission. Our work was discussed at two of their ultraviolet imaging team meetings. We had interest expressed by Dr. Richard Savage of Hughes in Colorado regarding applications of our techniques to images obtained by the DMSP satellite.

2.2 Other technology transfer and collaboration

Throughout this CESDIS project we benefited from the many contacts made at Goddard. For Dr. Ed Kemper we developed a new algorithm to enhance noisy X-ray images of diffuse X-ray scatterers. With Dr. Josephino Comiso we have had interactions that have resulted in a joint publication of application of statistical analyses comparing Synthetic Aperture Radar images with laser altimeter data.

Among others that we have had interactions with at Goddard are Dr. Dan Baker, Laboratory for Extraterrestrial Physics, Drs. Robert Price, Jim Tilton of Science Information Systems, Dr. David Leisawitz regarding astronomical applications, Drs. Jim Green, Bob McGuire, Owen Storey, Lloyd Treinish and Robert Crompton of NSSDC.

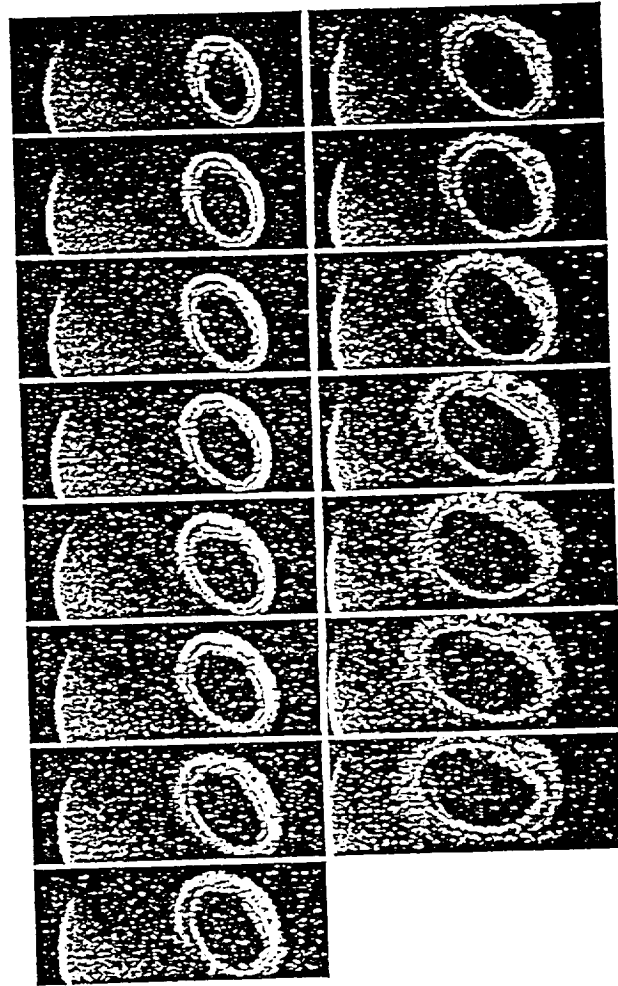


Figure 1

Part of the CDAW 9 dataset showing a sequence of fifteen DE-1 satellite images of the aurora. The results of automatic inner boundary estimation are overlaid.

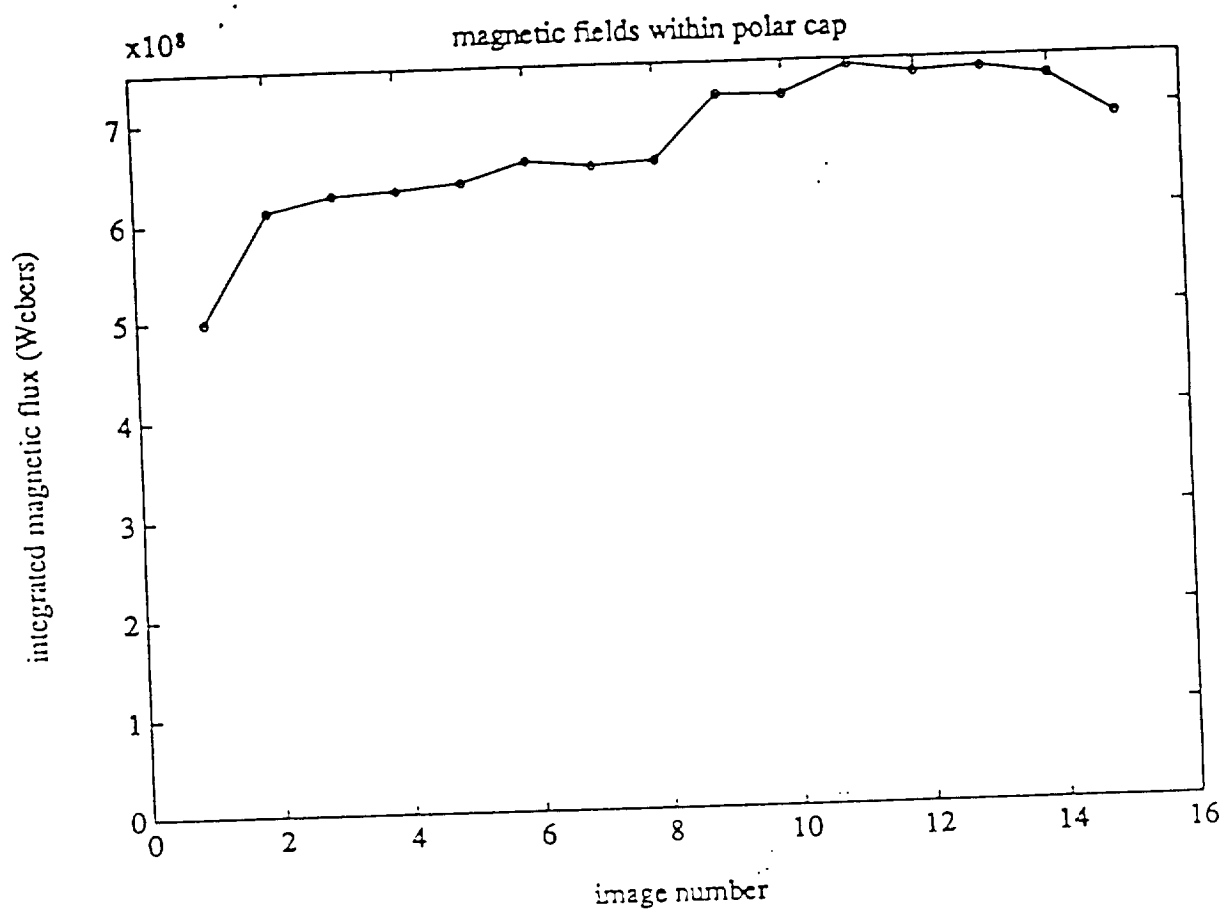


Figure 2

Time series plot of the integrated magnetic field intensity for the fifteen images in Figure 1.

CESDIS facilitated helpful interactions with Drs. Azriel Rosenfeld, Peter Meer and Behzad Kamgar-Parsi then of the University of Maryland. We were also happy to invite several people to CESDIS workshops. Dr. Peter Burt of SRI Sarnoff laboratory, Dr. Patrick Newell and Mr. Simon Wing of the Applied Physics Laboratory, Dr. Ramesh Jain of the University of Michigan and Dr. Glen Langdon of the University of California at Santa Cruz.

2.3 Technology transfer via educational activities

Educating the next generation of researchers was an important part of our technology transfer activities. Student Mihovilovic finished his PhD funded partially by CESDIS. Masters students Cecilia Han and Lalit Katragadda and summer students Steve Ross and Chacko Sonny contributed to the project with CESDIS funding. Several people volunteered their time for this project without any CESDIS funding. We wish to acknowledge them here: Jason Daida (has completed PhD in Electrical Engineering) who applied iterative segmentation techniques to the auroral images in order to improve the summertime scenes [Ref. 14], Raymond Wong (PhD candidate in Electrical Engineering) worked on a pattern recognition approach to image retrieval and Mr. Heping Zhang (has completed PhD in Statistics) who aided us briefly during the early stages of the aurora application in the use of Markov Random Field estimation.

Dr. Samadani taught twice a graduate image processing class at the University of California, Santa Cruz, and once at Stanford University. These three courses included examples of applications to several NASA remote sensing problems, including our CESDIS auroral image analysis work.

3 Conclusions

We made considerable progress in removing the bottleneck created by the manual extraction of boundaries from satellite images of the aurora. Our system allows the extraction of physically significant parameters from a much larger number of images than is feasible manually. Much larger scientific studies may now be conducted using our automated methods. The organization, search and retrieval of the images needed for these larger studies in turn became the new challenge that we addressed towards the end of our CES-

DIS research. We provided the software for image analysis to four different locations: the University of Michigan, under supervision of Dr. Clauer, the University of Iowa, under supervision of Dr. Frank, to the CESDIS computer center and to the NSSDC computer center. The last two centers are located at Goddard Space Flight Center.

4 Software

This section describes briefly the programs used to analyze the auroral images. For additional information about the software, contact the CESDIS office at Goddard.

In the main directory of the tree where the software resides, there are two files that new users should read. The first is the README file that contains an annotated listing of the tree and the second is the INSTALL file that describes installation of the software. The f77 and gnu C compiler are needed for compilation, as well as X11 software. A user familiar with Unix, X-Windows, C and C-shell scripts should aid the users during the installation process.

xwframe This program reads an image file in hips format from standard input (stdin) and displays it on the screen of a system running X Windows.

Usage : `xwframe < filename`

options :

`-n` will display the given string on the window top bar. It defaults to the name of the hips image (read from the header of the hips file).

`-x` defines the x location of the xwframe window.

`-y` defines the y location of the xwframe window.

xcolor This program allows the user to change the X Windows colormap that is shared by *xwframe*. Xcolor must be started before *xwframe* is called.

Usage : `xcolor`

maftohips This program reads a file in *maf* format from standard input (stdin) and writes the corresponding image in *hips* format to standard output (stdout).

Usage : maftohips < filename.maf > filename.hpl

correct This program converts a file from *maf* format to a format that is compatible with the way that data records are read in Fortran (*cmaf* format). The program appends at the beginning and at the end of each original record four bytes that contain the record length.

Usage : correct < filename.maf > filename.cmaf

read This program reads a file in *cmaf* format and saves the header information and (latitude, longitude) pairs for each pixel in the image as ASCII text to a file with extension PIX. It is hardwired to read from "tempor.maf" (*cmaf* format file!) and write the result to "tempor.PIX".

Usage : read

latlonhips This program reads a *PIX* file ("filename.PIX") and it generates two floating point hips files containing the latitude and longitude information. The two output files are called "filenamelat.hpl" and "filenamelon.hpl". These two images must be converted to byte hips format before they can be displayed by *xwframe*. The conversion and display can be done at once with the command `scale < filenamelat.hpl | xwframe` for the latitude image and similarly for the longitude image : `scale < filenamelon.hpl | xwframe`

Usage : latlonhips filename

readheader This program reads a *maf* file from standard input (stdin) and writes the header information in ASCII to standard output (stdout).

Usage : readheader < filename.maf > filename.hdr

polar This program converts an image in hips format to its polar representation. The center for the Cartesian to polar coordinates transformation is read from the file "filename.c0r0" that contains the x and y coordinates of the center in ASCII. The option -n allows to define the number of rows of the transformed image. The option -r allows to define the number of columns of the transformed image.

Usage: polar < filename.hpl > filename.p

options :

-n defines the number of rows of the output image.

-r defines the number of columns of the output image.

editor This program is used to edit/generate interactively auroral boundaries. It reads automatically the hips image ("filename.hpl"), and the inner and outer boundaries ("filename.insnk" and "filename.outsnk" respectively). It also uses the latitude and longitude information ("filenamelat.hpl" and "filenamelon.hpl" files respectively)

Usage: edit -f filename

options :

-f defines the filename

-cellsize defines the magnification factor for the image

find This program searches for the auroral boundaries. It reads the polar image from standard input (stdin). It also uses the latitude and longitude maps ("filenamelat.hpl" and "filenamelon.hpl" files respectively). The boundaries are saved to the files "filename.insnk" and "filename.outsnk". The program `real_area` can then be used to compute the area and total integrated magnetic field inside any of the boundaries.

Usage: find < filename.p > /dev/null

options :

-x use X graphical interface. By default, it runs on the background.

real_area This program computes the area and the total magnetic field inside boundary. The program reads the boundary file from "filename.snk" and it uses the latitude and longitude images ("filenamelat.hpl" and "filenamelon.hpl"). The files with the coefficients for the magnetic field model must be in the current directory. These files are `dgrf65.dat`, `dgrf75.dat`, `igrf45.dat`, `igrf55.dat`, `igrf85.dat`, `dgrf70.dat`,

dgrf80.dat, igrf50.dat, igrf60.dat and igrf85s.dat. The total number of pixels, total area in km^2 and the total integrated magnetic field are written to stdio and to a file called "filename.mag".

Usage : real_area filename > /dev/null

run_file.csh This shell file generates the *hpl*, *lat.hpl*, *lon.hpl*, and *hdr* files from a given *maf* file. The *lat.hpl* and *lon.hpl* files are saved in compressed format (using the standard *compress* Unix command).

Usage : run_file.csh filename

gen_polar.csh This shell is used to generate the polar plot and the *c0r0* files manually. The *hpl* file is displayed, then the user clicks in the center of the aurora and types in the center estimate coordinates (*c0,r0*). Using this location as the estimate of the aurora center the polar image is created with extension ".p".

Usage : gen_polar.csh filename

Glossary of file formats

maf DESAI image format.

cmaf DESAI image format corrected for proper handling by Fortran programs.

hpl HIPS image format. HIPS stands for Human Information Processing Laboratory's Image Processing System.

PIX File containing the header information plus (latitude,longitude) information for each pixel in ASCII format.

hdr File containing all the header information in ASCII format.

c0r0 File containing x and y coordinates of the estimate of the center in ASCII.

5 Personnel

The personnel that worked on this research were Professor G. Wiederhold as principal investigator from 1989 - 1991. Professor Wiederhold was involved in guiding the research and also in aid to CESDIS including proposal review and workshop participation. Professor M. Flynn was principal investigator during 1991 - 1993 and was involved in the management of this project. Dr. Samadani worked on the research throughout the funding period. He was responsible for overall supervision of the development of the techniques for auroral image analysis. Dr. Robert Clauer guided the geophysical aspects of the work while at Stanford. Dr. Clauer currently works at the University of Michigan. From Michigan, he continued to provide geophysical guidance through visits to Stanford and via electronic network collaboration. As noted above, several graduate students contributed to this research.

6 Publications and presentations

A list of publications from the CESDIS research is included below. Most of these reports are available from CESDIS as technical reports.

Our CESDIS work was advertised in three places: the cover of the program guide for SPIE's February 1991 Image Processing conference in Santa Clara shows a photograph from our CESDIS research, the USRA 20th anniversary publication included a reprint of the IEEE journal publication of our CESDIS funded research and we were interviewed about our CESDIS research for an article that appeared in the USRA Quarterly.

Publications and Papers Presented at Professional Meetings resulting from the CESDIS research

- [1] G. Wiederhold, J. Brinkley, R. Samadani and C.R. Clauer, "Model-Driven Image Analysis to Augment Databases", Invited paper in T. Kunii (editor), Springer Verlag, Tokyo, 1989, pp. 159-180.
- [2] R. Samadani, "A Tutorial on Image Processing and Computer Vision", in Advanced Computer Methods for Systematic Biology, John Hopkins press, 1993.

- [3] R. Samadani and C. Han, "Computer Assisted Extraction of Boundaries from Images", SPIE Electronic Imaging 1993 Symposium, Storage and Retrieval for Image and Video Databases conference, February, 1993, San Jose, California, Vol. 1908, pp. 219 - 224.
- [4] R. Samadani and L.K. Katragadda, "Content-Based Event Selection From Satellite Images of the Aurora", SPIE Electronic Imaging 1993 Symposium, Storage and Retrieval for Image and Video Databases conference, February, 1993, San Jose, California, Vol. 1908, pp. 50 - 59.
- [5] D. Mihovilovic and R. Samadani, "A Minimization-Pruning Algorithm for Finding elliptical boundaries in images with non-constant background and with missing data", SPIE Image Processing Algorithms and Techniques III, February 1992, San Jose, CA, Vol. 1657, pp. 546-557.
- [6] R. Samadani, "Adaptive snakes: control of damping and material parameters", SPIE conference, Geometric Models in Computer Vision, July 1991, San Diego, CA, Vol. 1570, pp. 202-213
- [7] R. Samadani, "Changes in Connectivity in Active Contour Models", Proceedings of the IEEE Workshop on Visual Motion, March 1989, Irvine, CA., pp. 337-343.
- [8] R. Samadani, D. Mihovilovic, C.R. Clauer, G. Wiederhold, J.D. Craven and L.A. Frank, "Evaluation of an Elastic Curve Technique for Finding the Auroral Oval from Satellite Images", IEEE Transactions on Geoscience and Remote Sensing, July 1990, pp. 590-597.
- [9] D. Mihovilovic A., R. Samadani and C.R. Clauer, "Evaluation of an Elastic Curve Technique for Finding the Auroral Oval from Satellite Images", Proceedings of the International Geoscience and Remote Sensing Symposium, July 1989, Vancouver, Canada, pp. 1268-1272.
- [10] R. Samadani, D. Mihovilovic, C.R. Clauer, G. Wiederhold, J.D. Craven and L.A. Frank, "A Computer Vision System for Automatically Finding the Auroral Oval from Satellite Images", SPIE/SPSE Conference on Image Processing Algorithms and Techniques, Feb.12-14, 1990, Santa Clara, California, pp. 68 - 75.
- [11] M.G. Walker, C.R. Clauer, R. Samadani, J.D. Craven and L.A. Frank, "Automated Analysis of Auroral Images" , American Geophysical Union Conference, 1987, San Francisco, California. See EOS Transactions, Vol. 68, No. 44, November 3, 1987, pg. 1436 for abstract.
- [12] C.R. Clauer, R. Samadani, D. Mihovilovic, J. Vesecky, P. Banks, G. Wiederhold, J. Craven and L. Frank, "Computer assisted analysis of auroral

images obtained from high altitude polar satellites", Presented at the sixth scientific assembly of IAGA, Exeter, U.K, August, 1989.

[13] C.R. Clauer, R. Samadani, D. Mihovilovic, J. Vesecky, P. Banks, G. Wiederhold, J. Craven and L. Frank, "Computer automated analysis of auroral images obtained from high altitude polar satellites", EOS, Trans. Amer. Geophys. Union, 70, 405, April, 1989 (abstract). Presented at the Spring Meeting of the American Geophysical Union, May, 1989.

[14] J. Daida, R. Samadani and J.F. Vesecky, "Adaptive Image Segmentation Applied to Extracting the Auroral Oval from Satellite Images", Proceedings of the International Geoscience and Remote Sensing Symposium, May 20 - 24, 1990, Washington D.C., pp. 1649 - 1650.

Other Presentations of our CESDIS research results

Presentations of the CESDIS research have been made at many places, including: NASA Goddard at various CESDIS seminars, and the Goddard Advances in Computer Science seminar, University of Iowa Physics department, University of Michigan Electrical Engineering department, University of California Santa Cruz, Computer Engineering department, IEEE Geoscience and Remote Sensing Society of Santa Clara, California, Stanford University seminars in Electrical Engineering, Geophysics and Earth Sciences and an NSF Workshop on advanced computer methods for biology in Napa, California. The other presentations at conferences are shown in the publications list above.



Report Documentation Page

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